STATUS OF MHTGR STEAM GENERATOR DESIGN IN THE UNITED STATES OF AMERICA

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Abstract

The optimization of steam generator designs for Modular HTGR (MHTGR) concepts represents an evolution from a technology and experience base developed in the U. S. and Europe as well as an adaptation of that base to the specific requirements of the Modular HTGR. The resulting steam generator concept thus meets the requirements of the Modular HTGR in a manner consistent with the state-of-the-art for nuclear heat exchangers and pressure vessels.

Preface

The content of the presentation is based upon information used for a presentation* at Geneva, Switzerland in June of 1986. Since the 1986 presentation, the emphasis of design activity has been on performance analysis and its relationship to three significant design criteria:

(1) tube stresses resulting from the interaction of tubes and support plates

(2) Bi-metallic weld temperature and

(3) stability of operation at low feedwater flow.

The results of these analyses highlight the need to fully understand the character of the inlet helium flow and temperature distribution, the mixing and possible bypass that occurs in the bundle and the degree to which such considerations can be accounted for by orifices in the tubes.

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* S.A. Caspersson, A.H. Spring and P. Burgsmüller, "Design Optimization of Steam Generators for Modular HTGR Concepts", presented at Fourth International ENS/ANS Conference (ENC-4), Geneva, Switzerland, June 1-6, 1986.

1. Introduction

Steam generators for the Modular HTGR are generally based on the technology and design solutions developed for Fort St. Vrain in the U. S. and THTR in Europe. References 1 and 2 describe, respectively, the Fort St. Vrain and THTR Steam Generators while a companion to this paper (Reference 3) summarizes the evolution of Sulzer's HTR Steam Generator technology.

In the discussion which follows, the relationship of the existing HTGR Steam Generator technology to the current Modular HTGR concept is described, the design for the MHTGR Steam Generator is described and it is compared to the Fort St. Vrain and THTR Steam Generators.

2. Optimization

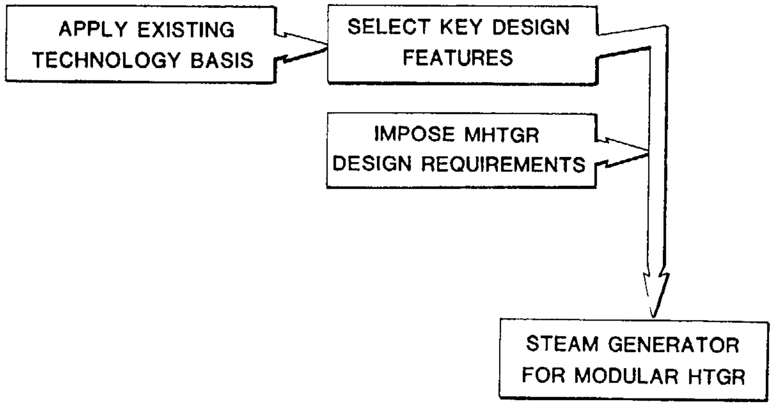
In developing a conceptual design for the MHTGR Steam Generator, the existing design and technology basis provides an evolutionary starting point for many basic design selections while the specific design requirements of the MHTGR lead to a definitive steam generator design. Figure 1 illustrates this optimization process.

3. Existing Technology Basis

For existing basis for MHTGR Steam Generators consists primarily of the Fort St. Vrain Steam Generator, the THTR Steam Generator and recent U. S. large HTGR design and technology development programs.

Figures 2 and 3 illustrate many of the basic design selections for HTGR Steam Generators, such as: helical tube bundle geometry, expansion zones leading in and out of the tube bundles, and support of the tubes by radially oriented plates. There is, however, considerable variance of the design details between the FSV and THTR Steam Generators owing to plant specific requirements and configuration differences.

The technology base for the MHTGR Steam Generator comes from over two decades of HTGR programs as noted by the categories of information on Figure 4.

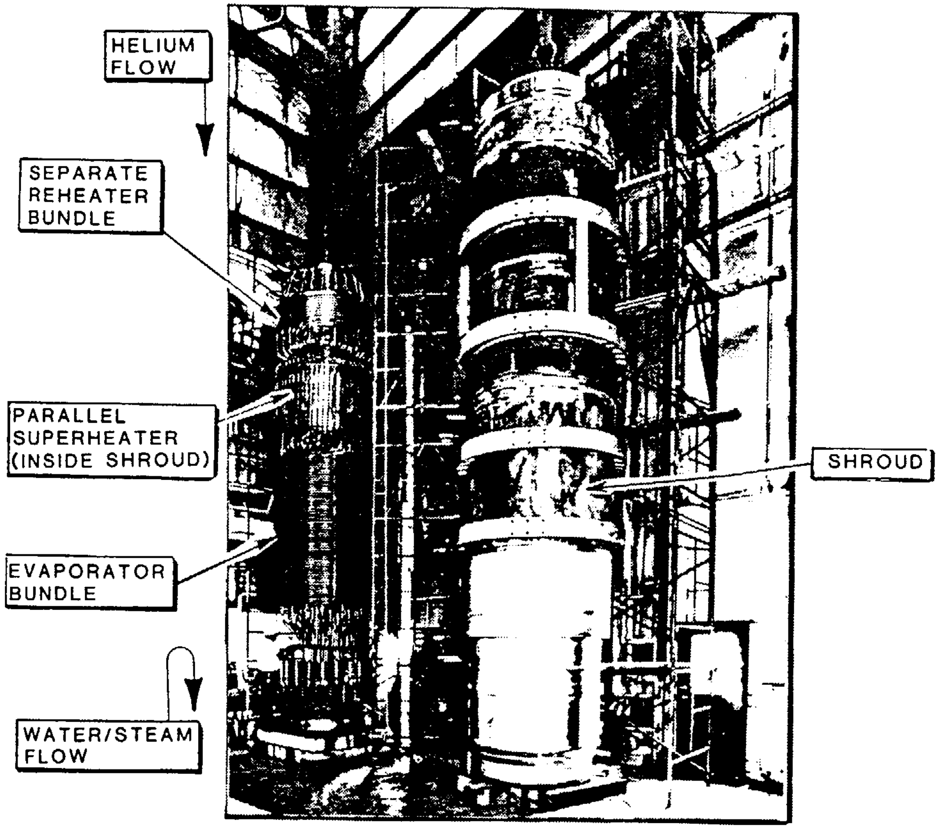


SIMPLIFIED OPTIMIZATION PROCESS

- FORT ST. VRAIN
- THTR
- US LARGE PCRV HTGR DESIGNS
- LWR STEEL TECHNOLOGY

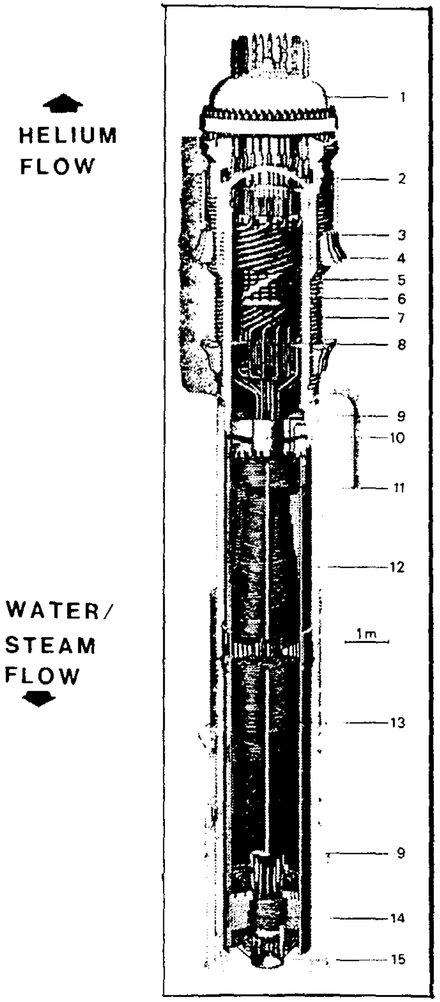
EXISTING TECHNOLOGY BASIS

FIG. 1.



FORT ST. VRAIN
STEAM GENERATOR

FIG. 2.



1 OUTER CLOSURE
2 INNER CLOSURE
3 REHEATER STEAM OUTLET
4 EXPANSION MODULUS
5 HP STEAM OUTLET
6 PRESTRESSED CONCRETE VESSEL PENETRATION
7 REHEATER STEAM INLET
8 FEED-WATER INLET
9 CENTRAL COLUMN
10 HELIUM OUTLET
11 HP-I-BUNDLE
12 OUTER SHROUD
13 HP-II-BUNDLE
14 REHEATER BUNDLE
15 HELIUM INLET

THTR STEAM GENERATOR

FIG. 3.

TECHNOLOGY BASE INCLUDES:

- MATERIALS DATA 2 1/4 Cr-1Mo
  ALLOY 800 H
- THERMAL HYDRAULIC DESIGN & ANALYSIS SOFTWARE
- STRUCTURAL DESIGN & ANALYSIS SOFTWARE
- OPERATING DATA
- FABRICATION PROCEDURES AND EXPERIENCE
- FLOW TEST DATA
- VIBRATION TEST DATA

FIG. 4.

4. Design Requirements for the MHTGR Steam Generator

Typical design conditions and configuration requirements for the MHTGR Steam Generator are listed on Figure 5. A significant departure from both FSV and THTR is the selection of a steel vessel for the helium pressure boundary as opposed to a pre-stressed concrete reactor vessel. This requirement introduces a new dimension, since that the steel pressure vessel is intended to operate at temperatures and pressures and with materials typical of LWR vessels. Hence, LWR vessel technology becomes a significant portion of the MHTGR technology base.

5. Description of Conceptual Design

Figure 6 shows the general configuration of the MHTGR Steam Generator and notes the main features and parameters of the modular concept. To provide a frame of reference, the MHTGR Steam Generator is compared to the FSV and THTR Steam Generators on Figure 7.

- THERMAL/HYDRAULIC PARAMETERS

• UNIT THERMAL RATING, MWt	350
• HELIUM INLET TEMPERATURE, °C(F)	686 (1266)
• FEEDWATER INLET TEMPERATURE, °C(F)	193 (380)
• STEAM TEMPERATURE, °C(F)	541 (1005)
• STEAM PRESSURE, MPa (PSIA)	17.3 (2515)

- CONFIGURATION REQUIREMENT
  - ONCE-THRU UPHILL BOILING INSIDE TUBES
  - LOCATED IN STEEL PRESSURE VESSEL ADJACENT TO REACTOR VESSEL
  - FACTORY ASSEMBLY
  - TRANSPORT WITH EXISTING CONSTRAINTS

FIG. 5. DESIGN REQUIREMENTS FOR THE MHTGR STEAM GENERATOR

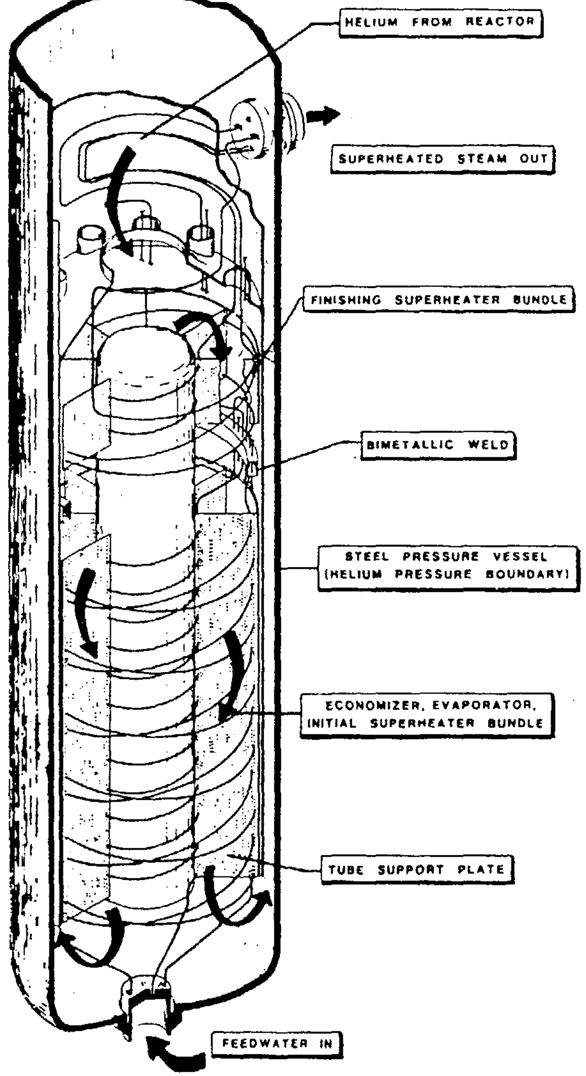
MAIN FEATURES

- UPFLOW BOILING INSIDE TUBES
- TWO HELICAL BUNDLES
  - ECONOMIZER / EVAPORATOR /INITIAL SUPERHEAT (EES)
  - FINISHING SUPERHEAT (FS)
- MATERIAL CHANGE (BIMETTALLIC) BETWEEN EES AND FS
- TUBES SUPPORTED BY RADIALLY ORIENTED PLATES
- EACH TUBE CIRCUIT IS CONTINUOUS FROM TUBESHEET TO TUBESHEET

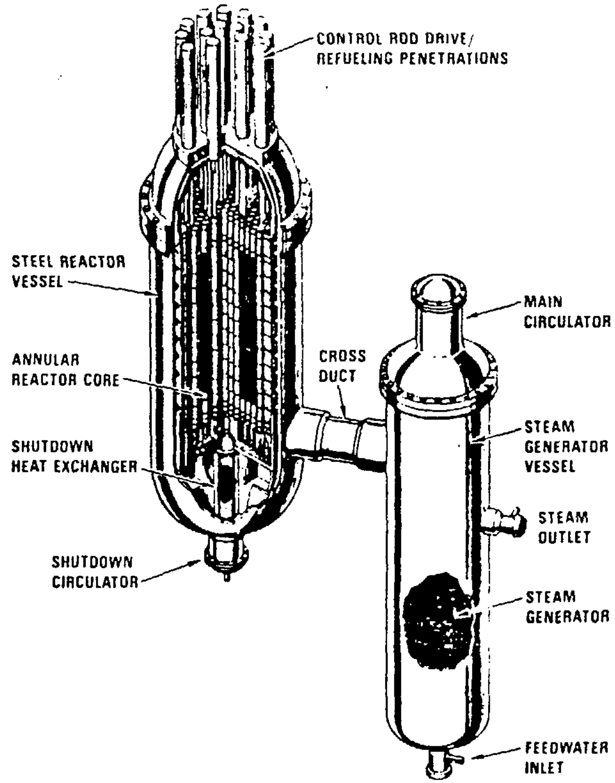
- APPROXIMATE ENVELOPE

• DIAMETER, M(FT)	4.2 (13.7)
• HEIGHT, M(FT)	26.5 (86.8)
• WEIGHT, METRIC TONS (US TONS)	466.3 (514)

MHTGR STEAM GENERATOR CONCEPTUAL DESIGN



MHTGR STEAM GENERATOR



MHTGR GENERAL CONFIGURATION

FIG. 6.

	FSV	THTR	MODULAR HTGR
OVERALL HEIGHT M(FT)	16.8 (55.2)	18.6 (61)	26.5 (86.8)
OVERALL DIAMETER, M(FT)	1.7 (5.6)	2 (6.6)	4.2 (13.7)
NUMBER PER REACTOR	12	6	1
APPROX. WEIGHT METRIC TONS (US TONS)	22.7 (25)	65 (71.6)	466.3 (514)
THERMAL RATING / UNIT, MW	28.5	128	350
HELIUM INLET TEMP, °C(F)	775 (1427)	750 (1382)	685.6 (1266)
STEAM OUTLET TEMP, °C(F)	540.6(1005)	550 (1022)	540.6 (1005)
STEAM PRESSURE, bar (PSIA)	173.2 (2512)	186.2(2700)	173.4 (2515)
NUMBER OF TUBE CIRCUITS	18/54	40/80	350

COMPARISON OF HTGR STEAM GENERATORS

FIG. 7.

REFERENCES

1. Quade, R. N., et al, "The Design of the Fort St. Vrain Steam Generators", Nuclear Engineering and Design, 26 (1974), p. 118 - 134.

2. Bachmann, U., "Steam Generators for the 300 MWe Power Station with a Thorium High Temperature Reactor", Sulzer Technical Review, 4/1975 (Volume 57), p. 189 - 194.

3. P. Burgsmuller, H. W. Fricker, M. Weber, "Steam Generators and Heat Exchangers for High Temperature Reactors", paper to be presented at the Fourth International ENS/ANS Conference (ENC-4), June 1 to 6, 1986, Geneva, Switzerland.

MAIN CHARACTERISTICS AND DESIGN FEATURES OF STEAM GENERATORS FOR VG-400 PLANT

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Abstract

The description of a steam generator for the VG-400 plant performed in two variants depending on a heat-exchange surface arrangement: one-bundle coil and module-cassette construction is given.

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1. Main Requirements for Steam Generator

In developing a detail design of a steam generator for a pilot-commercial installation with VG-400 reactor the analysis and generalization of both home and available foreign experience of designing and operation of steam generators for NPI with HTGR was accomplished. In NPP with HTGR operating now in the world use of steam generators which apply as a heat surface tube bundles from multiple helical concentrically located cylindrical coils with a large arrangement diameter. A manufacture of similar tube bundles requires a special complicated equipment and long production cycle [1] . For the installation with VG-400 reactor steam generators are developed with an other scheme of heat-exchange surface which is to be described below. Main requirements for the VG-400 installation steam generator design are formulated as follows:

- The design reliability ensuring a long operation of steam generator (up to 100.000 hours) in all operating conditions of